Planning and scheduling in process industries considering industry-specific characteristics

Kilic, Onur Alper

Publication date:
2011

Chapter 6

Conclusions and directions for further research

Abstract. *The final chapter presents the research findings of the thesis, discusses the conducted research and points out some directions for future research.*

This thesis is concentrated on planning and scheduling in the process industry. The work carried out in the thesis stands apart from the existing literature by considering industry-specific characteristics of processing systems. A specific emphasis is laid on the combinations several industry-specific characteristics and the interactions between them. The main research objectives of the thesis are defined as: (i) to contribute to the development of mathematical models that can be used as decision aids in scheduling processing systems with industry-specific characteristics, and (ii) to provide some insight into the order acceptance function in the process industry with respect to limitations in raw material availability. The thesis is organized as a collection of research papers which attend to these research objectives. The first research objective is confronted in Chapter 2, Chapter 3 and Chapter 4. These chapters addressed particular scheduling problems originating from specific production environments and developed models and methods thereof. The second objective is confronted in Chapter 5. This chapter considered the order acceptance problem in a processing system subject to limited raw material availability and variable raw material quality.

The research papers included in this thesis addressed and elaborated mathematical problems inspired by specific production environments. These problems differ from each other in terms of their technological specifications and managerial objectives. The extent to which the proposed models and methods are applicable in other production environments strongly depends on the degree of contingency between the characteristics of the proposed approaches and the underlying production environments. This thesis exercised both case-specific and general approaches. For example, Chapter 3 adopted the general discrete time formulation of batch processes which is not tailor-made for a specific application. Chapter 4, however, presented an approach building on the structure of the underlying production environment. It is obvious that case-specific approaches are more efficient than general approaches since they make use of the specific characteristics of the targeted production environments. However, often they are not easily applicable in problems originating from different production environments. In the following, the results are summarized and directions for further research are suggested for each individual chapter included in the thesis.

Chapter 2 addressed a scheduling problem confronted in two-stage food processing systems with production and storage capacity limitations. The problem also entails the use of flexible product recipes, and involves the selection of a set of intermediates and end product recipes characterizing how those selected intermediates are blended into end products. In this regard, the problem is an extension of the production lot scheduling problem with integrated design decisions. A comprehensive mixed integer linear programming (MILP) model is developed for the problem which integrates the decisions regarding production schedule as well as the specifications of intermediates and end products with the objective to minimize total operational costs. The model is then applied to a data set collected from a real-life case. The results derived from the numerical study are assessed to better understand the dynamics of the problem. It is shown that cost parameters and capacity limitations have significant effects on the production schedule and the selection of product recipes. It is observed that the fixed production setup costs and inventory holding costs can be regulated by altering the number of intermediates and end product recipes as well as the production schedule. Also, the trade-offs between capacity limitations and operational costs are investigated. It is shown that the limitations on production and storage capacities interact with each other. Thus, whether a particular type of capacity limitation is binding depends on its relative magnitude. It is observed, for the case example, that the storage capacity limitation is binding whereas the processing and the blending capacities are not. On this account, the extent of possible cost reductions that can be achieved by expanding the storage capacity is investigated. The results showed that the cost reduction due to an extra storage unit is not decreasing on the actual storage capacity because of the interactions between the decisions on the selection of intermediates and the scheduling of production operations. This points out that a careful investigation is required when expanding the storage capacity. Although the research carried out in this chapter particularly targets the food processing industry, it takes into account several characteristics common in many other processing systems. Hence, it could be possible to adopt the proposed model to be used in different production environments. A possible example could be the batch processing counterpart of the flow processing system addressed in this chapter. Also, the proposed approach can be extended by relaxing some of its restrictive assumptions. The problem is analyzed under a common cycle scheduling policy. This policy is widely used in practice due to its simplicity. Nevertheless, it is known that it may perform badly in some production settings. Thus, the problem can be analyzed under more sophisticated scheduling policies. Another restriction is that the storage units are assumed to be identical and they can only be assigned to a single type of intermediate. However, in many practical cases storage units are different in terms of their volume, and it may be possible to use storage units for several types of materials. Therefore, it is important to direct further research efforts towards these cases.

Chapter 3 is concentrated on the detailed short-term scheduling problem in multiproduct/multipurpose batch processes. The work carried out in this chapter extends the conventional discrete time MILP formulation for scheduling batch processes by introducing storage capacity and storage time limitations. These limitations are very common in many industries involving perishable intermediates and end products. A mathematical model is developed for the problem which is shown to be capable of handling various storage configurations involving single/multiple and dedicated/multipurpose storage vessels. By means of a numerical study it is illustrated that storage capacity and storage time limitations have significant effects on production and storage operations and significantly degrade the cost performance of batch processing systems. Also, it is shown that these effects can be averted to some extent by means of using multipurpose storage vessels. The proposed approach builds on the general discrete time formulation of batch processes. There is a variety of studies based on this formulation which aim at capturing different characteristics of batch process scheduling problems. Therefore, the proposed model can easily be extended by employing methods already suggested in the literature. Among those extensions the integration of sequence- and frequency-dependent setups, the use of time-based objective functions, and the application of reformulations designed to enhance the computational performance can be mentioned. An important direction for further research is to adopt the proposed batch process model to account for continuous and semi-continuous processes where storage limitations addressed in this chapter are of concern. Also, research efforts can be directed towards modeling the problem by using a continuous time formulation. Although continuous time formulations have various drawbacks, in principle they are more realistic since they yield more precise solutions.

Chapter 4 investigated a real-life scheduling problem which originates from an evaporated milk processing system. The system has a semi-continuous structure. There are two continuous production stages: processing and packaging. These stages are connected by intermediate storage where materials are batch-wise standardized. The problem requires the consideration of the industry-specific characteristics of the underlying production environment. These involve traceability requirements, and time- and sequence-dependent cleaning of production units. These characteristics result in a computationally challenging scheduling problem which also requires an efficient, yet flexible modeling approach. This chapter contributes to the literature by presenting such a mathematical approach. The proposed approach decomposes and solves the overall problem in two-phases where the specifications regarding material flows are determined and a complete production schedule is developed in succession. The decomposition scheme not only simplifies the overall problem but also facilitates modeling traceability requirements by isolating material flow and scheduling decisions. The respective sub-problems concerning the two phases of the decomposition are formulated by using different modeling paradigms. The first sub-problem is formulated by using MILP. The second sub-problem, however, is formulated by employing constraint programming (CP). The approach is tested on a data set collected from a real-life evaporated milk plant and shown to be efficient. The novelty of the approach lies in coordinating the system as a whole. The majority of research contributions on scheduling food processing systems concentrate on a single production stage which is regarded as the bottleneck. However, this could only be justifiable when product and routing variety is fairly limited. This chapter mainly concentrated on the evaporated milk production process. Although this production environment is not very common within the domain of the processing industry, there are many examples of food processing systems characterized by a make-and-pack configuration. The proposed approach can be particularity appealing for such processing systems. Furthermore, it could be possible to make use of the flexibility of the current modeling scheme in order to address further elements which could be of interest in the food processing industry. For instance, the concept of chain dispersion – a measure in which production batches are spread among different customers – can easily be integrated into the proposed approach. A variety of potential directions for further research can be acknowledged. The decomposition approach taken in this chapter, in principle, leads to sub-optimal schedules. Thus, it is important to focus on approaches which can integrate the two sub-problems which are solved sequentially in the current study. Also, the computational performance of the scheduling problem comprised in the second phase can be increased by embedding more sophisticated search procedures into the CP model. Another important research direction is the consideration of possible revisions in customer orders prior to their dispatch. A possible proposal towards this issue is to integrate safety stocks and/or safety times into the scheduling approach.

Chapter 5 addressed the order acceptance problem in a food processing system where a single raw material is processed into a variety of different end products. The essence of the problem lies in the limited availability of the key raw material and the variability in yield. The customer orders for end products arrive following a stochastic process. The objective is to maximize the expected total revenue by making the optimal admission decisions for incoming orders. This chapter demonstrated that the problem can be modeled as a single resource capacity control problem, and it can be solved by means of dynamic programming (DP). However, since the structure of the optimal admission policy is found to be very complex for practice, a threshold-based heuristic policy is developed. An extensive numerical study is then conducted to compare the optimal admission policy against the new heuristic policy. The first-come-first-served policy is also included in the numerical analysis in order to reflect upon the case where no explicit admission policy is employed. This also helped to point out the cases where admission policies are critical. The results of the numerical study revealed that the heuristic policy performs very good on the overall. Also, it is observed that employing the optimal admission policy is relatively critical when the availability of the key resource is very limited, the variety of the type of customer orders is large, and the yield variability is low. The study carried out in this chapter has two main limitations. The proposed approach essentially neglects the production capacities and lead-times. Thus, the results derived in this chapter do not immediately apply to cases where production capacities are strictly limited and/or lead-times are significant. Thus, it is important to consider the problem where admission decisions must be taken in connection with both the raw material availability and the workload of the system. Nevertheless, it could be justifiable to expect that the importance of limited raw material availability diminishes in such cases since this limitation is an issue only if there is sufficient production capacity to process the raw material. Another limitation of the current study is the consideration of a single key raw material. In many production environments several raw materials are processed into end products all together. Thus, it is important to extend the current analysis to account for such systems.